



## Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at <http://about.jstor.org/participate-jstor/individuals/early-journal-content>.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact [support@jstor.org](mailto:support@jstor.org).

## ON THE EFFECT OF TEMPERATURE ON THE DEVELOPMENT OF ANIMALS.

FRANK R. LILLIE AND F. P. KNOWLTON.

PROTOPLASM exercises its functions only within a certain range of temperature ; the range extends from a minimum temperature where its functions may be said to begin<sup>1</sup> to a maximum above which occurs heat rigor and death, through an optimum which lies nearer the maximum than the minimum.<sup>2</sup> The intensity of any function increases from the minimum to the optimum temperature and then, as a rule, decreases to the maximum, though never to the level of the minimum. This temperature influence is especially well marked in the case of the *formative functions* of protoplasm, and although the number of authors who have noted this is very great, and although use is often made of it to facilitate observation, yet we have no adequate *quantitative* study of its effect in animals. The influence of temperature on growth in plants has, on the other hand, been carefully determined.

The effect of temperature on development in animals is two-fold, — on the *rate* and on the *form*. The latter effect is produced only by temperatures above the maximum or below the minimum. *In this sense, then, the minimum temperature for the whole development is the lowest and the maximum the highest at which normal development may occur.* The terms maximum and minimum will be used in this sense throughout this paper.

The effect of temperature on the rate of development involves two variants, time and extent, which are directly proportional to each other. By making either of these a fixed quantity we can measure the effect of the different temperatures in terms of the other. It is generally advisable to fix the *extent* and to measure the times at different temperatures, because it is not possible, as a rule, to express the differing

<sup>1</sup> We do not mean to imply that there is absolutely no metabolism at sub-minimal temperatures.

<sup>2</sup> See Davenport, *Experimental Morphology*, vol. i, p. 227.

extents of development in the same time at different temperatures in terms of each other: if for instance we discover that at a certain temperature the egg of the frog develops in twenty-four hours to the blastula and at another temperature to a later stage of gastrulation, we cannot express the effect of the increase in temperature quantitatively; but if, on the other hand, a fixed extent of development takes two days at one temperature and one day at a higher temperature, the effect of the increase in temperature is given quantitatively. However, in the case of mere growth in bulk or length, the *extents* at different temperatures within the same period of time can be directly compared.

In our study of the effects of temperature on development we have included (1) the *regeneration* of *Planaria torva*; (2) the cleavage and gastrulation of *Amblystoma* and the frog; and (3) the rate of growth of the tail of tadpoles of the frog and toad. The observations made have been much more numerous and have taken up much more time than the tables would lead one to suspect; this is due to the necessity of repeating observations to secure averages so as to eliminate the factor of individual variation, and to the great mortality at high temperatures. The temperatures below 22° C. are in all cases averages, owing to the impossibility of securing perfectly uniform low temperatures during the time occupied by the experiments. The average temperature was calculated from daily readings in the longer experiments, and from more frequent readings in the shorter ones; the variation from the average was rarely more than one degree either way.

### 1. *Planaria torva*.

*a. Normal Temperature Range.*—The animals were cut transversely through the middle of the body, thus dividing the pharynx. The time of regeneration of a complete head on the posterior half at different temperatures was then measured.

From the table it is seen that the lowest average temperature at which regeneration took place was 3° C.: of six specimens at this temperature only one regenerated at all, and in

AVERAGE TEMPERATURE.	AVERAGE TIME OF REGENERATION.	NUMBER OF OBSERVATIONS.
3° C.	180 days (incomplete)	1
9°	46.6 "	5
13°	21.5 "	6
14°	17.8 "	6
21°	7.3 "	6
26°	6 "	4
28°	5 "	16
29.7°	4.6 "	8
31.5°	8.5 "	9

TABLE I. — Table showing the time of regeneration at different temperatures of the posterior half of *Planaria torva*.

six months the eyes and brain were still incomplete. Three of the others died before the six months were up; two lived and showed no signs of regeneration, though they were responsive to stimuli all the time. These two were then put at room temperature, and one regenerated fairly normally, while the other showed no sign of regeneration, though it remained alive for several days.

The optimum temperature is 29.7° C., and the time of regeneration at this temperature 4.6 days, the fortieth part of the time at 3° C. At 31.5° C. regeneration was slower, 8.5 days.

The curve which follows (Fig. 1) shows the law of rate of increase.

*Between the minimum and the optimum the rate of decrease in time (increase in rapidity) of development diminishes with each degree rise in temperature.* Let  $x$  equal the decrease in time for each degree increase of temperature, then :

From	3° to 9° C.,	$x = 22.23$ days.
"	9° " 13° C.,	$x = 6.275$ "
"	13° " 14° C.,	$x = 3.7$ "
"	14° " 21° C.,	$x = 1.5$ "
"	21° " 28° C.,	$x = .329$ "
"	28° " 29.7° C.,	$x = .235$ "

TABLE II.

*b. Subminimal and Supramaximal Temperatures.* — Very little effect was observable in the case of the subminimal temperatures. Some of the anterior halves showed a slight ten-

dency to form a bifid tail at  $3^{\circ}$  C.; but the process was slow and never went very far.

At temperatures above the maximum no abnormalities were found; at  $32^{\circ}$  the planarians regenerate partly; small eye-spots

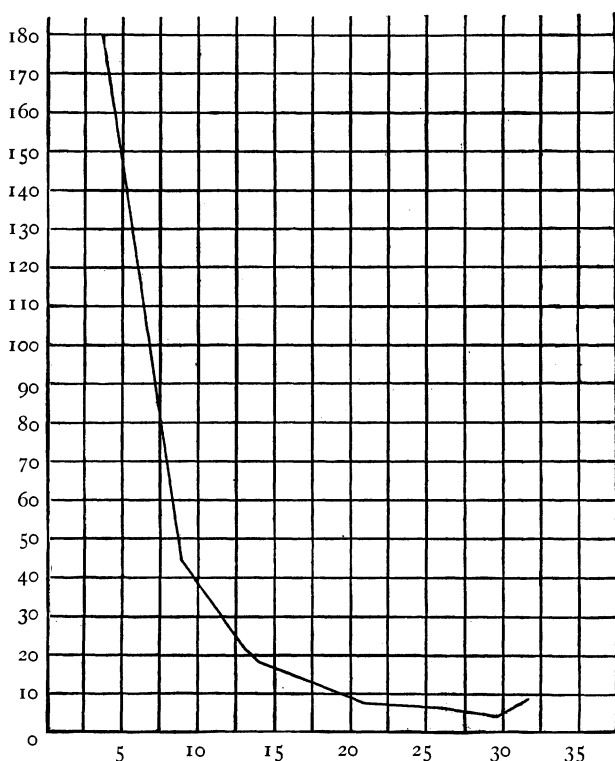


FIG. 1. — Curve of regeneration of the posterior half of *Planaria torva* at different temperatures. The ordinates measure time in days and the abscissae temperature in degrees Centigrade.

may appear, and death occurs in about six days; at  $33^{\circ}$  there was very slight regeneration, the animals dying within three days. At  $34^{\circ}$  and above there was no regeneration, and death came on rapidly.

## 2. The Early Development of *Amblystoma tigrinum* and the Frog (*Rana virescens*).

The eggs of *Amblystoma* are laid in March, often before the ice is entirely out of the ponds, when the temperature of the

water is not more than  $3^{\circ}$  or  $4^{\circ}$  C. The weather usually remains cool for at least a month after the laying of the eggs, so that during the early development the water never becomes very warm. The eggs of *Rana virescens* are not laid until the water is much warmer; thus they are never exposed to such low temperatures as *Amblystoma*.

*a. Normal Temperature Range.*—The extent of the early development measured in both forms was from the first or second cleavage to the last stage of disappearance of the yolk plug; these periods were selected as being most sharply marked ones; and the time occupied even at the optimum is sufficiently long to reduce the amount of error to a very small proportion of the total time involved.

AVERAGE TEMPERATURE.	AVERAGE TIME OF DEVELOPMENT.	NUMBER OF OBSERVATIONS.
$4^{\circ}$ C.	288 hours	2
$8^{\circ}$	210 "	4
$9.5^{\circ}$	139.2 "	5
$13^{\circ}$	96 "	2
$14^{\circ}$	90 "	2
$18^{\circ}$	60 "	3
$22^{\circ}$	40 "	6

TABLE III. — Table of the time of development of the ova of *Amblystoma tigrinum* from the first cleavage to the last stage of disappearance of the yolk-plug. One observation does not mean necessarily a single egg, but often all the eggs of a bunch.

AVERAGE TEMPERATURE.	AVERAGE TIME OF DEVELOPMENT.	NUMBER OF OBSERVATIONS.
$4^{\circ}$ C.	471 hours	1
$8.75^{\circ}$	192 "	1
$12.12^{\circ}$	126 "	2
$16^{\circ}$	60 "	3
$22^{\circ}$	27.5 "	2
$24^{\circ}$	25.5 "	2
$26^{\circ}$	21.5 "	1

TABLE IV. — Table of the time of development of the ova of *Rana virescens* from the first, second, or third cleavage to the last stage of disappearance of the yolk-plug. Each observation means at least 30 eggs. The period between the first and third cleavages is relatively so short that it may be ignored in comparison with the whole time involved.

It will be noticed that the form of the curve is similar to the temperature regeneration curve of *Planaria*. The angle in the curve of *Amblystoma* would probably disappear with a sufficiently large number of observations ; that is, it is prob-

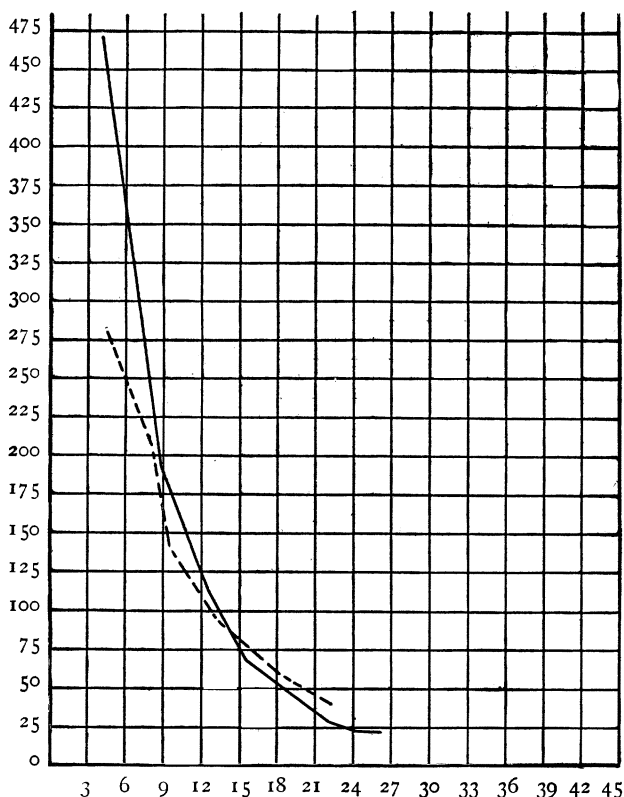


FIG. 2. — Curves showing the effect of the normal temperature range on the early development of *Amblystoma* and the frog constructed from the above tables. The broken line is the curve of *Amblystoma*. The ordinates give the time in hours, 25 hours for each abscissa; and the abscissae represent degrees Centigrade, 3° for each ordinate.

ably due to individual variation in the eggs observed. It is important to notice that the optimum and maximum temperatures actually coincide. This is due to the difference in temperature range of the dark and light hemispheres ; the cells of the light hemisphere are much more easily affected by low and high temperatures than those of the dark (see section on sub-minimal and supramaximal temperatures). The cells of the

dark pole would probably show a maximum above the optimum, and similarly for the white ; but we are not able to prove this. It is also conceivable that the coincidence of optimum and maximum is due to the complexity of the processes involved, the temperature range possibly differing for the different factors concerned, such as cleavage, invagination, differentiation, etc.

Let  $x$  equal the decrease in time for each degree increase in temperature; the next table shows its value for *Amblystoma* and the following one for the frog.

4° to 8° C.,	$x = 19.5$ hours.
8° " 13° C.,	$x = 22.8$ "
13° " 18° C.,	$x = 7.2$ "
18° " 22° C.,	$x = 5$ "

TABLE V. — *Amblystoma*.

4° to 8.75° C.,	$x = 58.7$ hours.
8.75° " 12.12° C.,	$x = 23$ "
12.12° " 16° C.,	$x = 16.5$ "
16° " 22° C.,	$x = 5.4$ "
22° " 26° C.,	$x = 1.5$ "

TABLE VI. — Frog.

The same law holds as for *Planaria*: between the minimum and the optimum the *rate* of decrease in time of development diminishes with each degree rise in temperature.

Below 14° eggs of *Amblystoma* develop more rapidly than those of the frog, and above less rapidly; *see curves* (Fig. 2). The eggs of the frog also develop above the maximum for *Amblystoma*. This is undoubtedly an inherited effect of the different temperatures to which the eggs are normally exposed, as noted before.

*b. Subminimal and Supramaximal Temperatures.*— Subminimal temperatures have the same effect on the cleavage of the eggs of both forms. At 0° C. cleavage is entirely inhibited. If the eggs of *Amblystoma* were put in a vessel containing ice and the vessel placed on ice in the refrigerator, cleavage was inhibited entirely or to a great extent in the white hemisphere, though it went on slowly and fairly normally in the dark hemisphere; death occurred before gastrulation, the temperature being about 1° C. The same effect was produced in eggs of the



frog at 2° to 3° C. At this temperature some of the eggs of the frog developed further, but always abnormally. The abnormalities produced were of the same nature as those described by Morgan and Tsuda ('94), by Hertwig ('94a) and by Gurwitsch ('96) in their studies on the effect of solutions of halogen salts of sodium and lithium; that is to say, abnormalities in the region of the blastopore, principally *spinae bifidae*. No anencephalic monsters were found.

Supramaximal temperatures have much the same effect, but the abnormalities are much more pronounced, owing partly to the fact that the embryo could be reared to a much later stage. *In both cases the effect is undoubtedly due to the greater sensitiveness both to subminimal and supramaximal temperatures of the cells of the white hemisphere*, as both Hertwig and Gurwitsch have remarked. The greater sensitiveness of the white cells is due to the relatively greater amount of yolk in them.

3. *The Growth in Length of Tadpoles of the Frog (Rana virescens) and Toad (Bufo lentiginosus) at Different Temperatures.*

a. *Normal Temperature Range.*—The tadpoles of the frog and toad were taken as soon as hatched (at the temperature of the room, 18–20° C.), and two measurements were made of each with the ocular micrometer under a very low power of the compound microscope (13.5 divisions = 1 mm.); the first measurement was the length of the tail *from the anus*, the second the total length. By subtracting the first measurement from the second we could get the length of the head and trunk, but this has not been included in the tables. At the end of 24 hours the measurements were repeated. The tables give the difference between the first and second measurements, that is, the growth in length in 24 hours. The growth in length of the trunk is very variable, owing to the fact that it is increasing at the same time in breadth as well as in depth, and more so than in length. The growth of the tail, on the other hand, is almost purely growth in length, so it alone is represented in the form of a curve. The tadpole is

subsisting entirely on its yolk supply during the time of the measurements, therefore the factor of variable food supply is eliminated. Thus the figures for growth in length of the tail represent only the effect of the different temperatures, excepting naturally individual variations which are partially eliminated by the averages.

AVERAGE TEMPERATURE.	AVERAGE GROWTH.		OBSERVATIONS.
	TAIL.	TOTAL.	
9.27° C.	2.27 units	4.5 units	2
11°	3.16 "	5.33 "	3
14.62°	3.75 "	4.27(?) "	2
18°	6.5 "	9.5 "	1
20.83°	11.16 "	19.83 "	3
25.27°	22.75 "	31.5 "	2
28°	30 "	40 "	1
29°	33.5 "	48 "	1
30°	38 "	47 "	1
31.3°	30.8 "	40.16 "	3
33°	28 "	43.5 "	1

TABLE VII.—Growth in length of frog tadpoles in 24 hours at different temperatures. 13.5 units equal 1 mm.

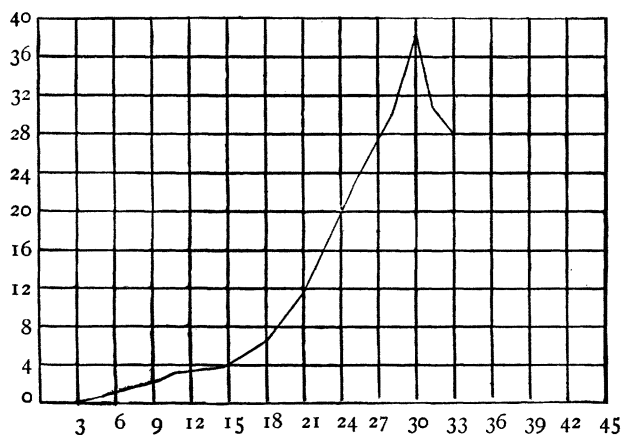


FIG. 3.—Curve of growth of the tail of frog tadpoles constructed from the above table. The ordinates represent units (13.5 = 1. mm.) of growth and the abscissae degrees Centigrade.

Comparison of the curves and of the tables shows that the growth of the frog tadpole begins at a lower temperature than

AVERAGE TEMPERATURE.	GROWTH OF TAIL.	TOTAL GROWTH.	OBSERVATIONS.
9° C.	.5 units	3 units	I
11.6°	2.66 "	5.33 "	3
14°	6.5 "	15.5 "	I
16.3°	7.8 "	16.3 "	3
19.9°	10.16 "	21.16 "	3
24.8°	28 "	41.3 "	2
26°	34 "	39 "	I
29°	41 "	56.7 "	5
30.1°	41.6 "	56.8 "	5
31°	44 "	55 "	I
32°	37.5 "	55.5 "	I
33°	41.5 "	58 "	I
35°	44 "	57 "	I

TABLE VIII. — Growth in length of toad tadpoles at different temperatures. 13.5 units equal 1 mm. The last three readings are from one lot of tadpoles, and their difference from the others represents individual variation. They are not included in the curve.

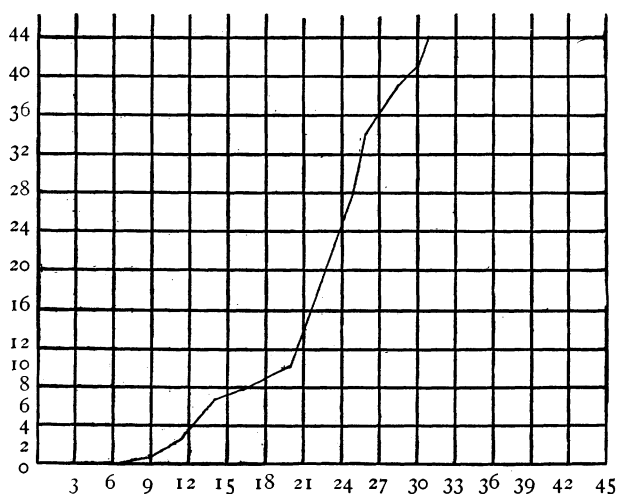


FIG. 4. — Curve of growth of the tail of toad tadpoles constructed from the above table. The ordinates represent units (13.5 = 1 mm.) of growth and the abscissae degrees Centigrade.

the toad tadpole and that the latter continues to grow at a higher temperature (see table, not shown in curve) than the former. This is correlated with the fact that the eggs of the toad are laid later than those of the frog and generally in smaller, shallower pools, the temperature of which is relatively high; this has caused acclimatization to a higher range.

There is a slight decrease in the rate of growth beyond the optimum in the case of the tadpole of the frog. This is probably also the case with the toad, but our observations are not sufficiently extensive to show it, for the material gave out before it could be tested.

In both the frog and the toad tadpoles the rate of increase is relatively slow up to about  $20^{\circ}$ , when the rate becomes suddenly much more rapid. This is very marked in the tables; for instance, the elongation of the tail in the frog tadpole is 11.16 units at  $20^{\circ}$  in 24 hours, at  $25^{\circ}$  it is 22.75, or more than twice the amount at  $20^{\circ}$ ; in the toad tadpole the figures are 10.16 and 28 at approximately the same temperatures, an even more striking increase. The curves show this too; see especially the curve for growth in length of the tail of the toad tadpole. Why there should be this sudden change in rate between  $20^{\circ}$  and  $25^{\circ}$  is difficult to determine.

*b. Subminimal and Supramaximal Temperatures.*—As was to be expected, we found that very low temperatures—that is, below  $3^{\circ}$  in the case of the frog and  $6^{\circ}$  in the case of the toad—entirely inhibited growth. But we obtained one result which was entirely unexpected: *at about  $2^{\circ}$  C. there was an actual shortening in the tadpoles of the frog in twenty-four hours*; this decrease in length was very slight, but sufficiently well marked to be plainly discernible, varying from .5 to 2 units. It was most plainly shown in the youngest tadpoles. We have come to the conclusion that the decrease is due to a diminution in the turgor of the cells, caused by diminished endosmosis dependent either on the low temperature directly, or on the non-production of the active endosmotic substance within the cell, or on both factors combined. In this connection the observation of Davenport ('97) that “the immense increment in weight which accompanies the outlining of the form of the larva (tadpoles of frog and toad) and its organs is due almost solely to absorbed water” is of importance.

Temperatures above the maximum for normal growth resulted as a rule very quickly in death of the tadpoles. There was, however, a marked tendency in the case of those that survived a sufficiently long time for the tail to grow out at an

angle with the axis of the trunk generally inclined ventrally, rarely dorsally, never laterally.

#### 4. General.

This is the first time, I believe, that an attempt has been made to represent in the form of a curve the effect of temperature on the rate of development in animals, or that sufficiently extensive observations have been made to render this possible. The literature on the subject is mostly old and of historic interest only; the principal papers are cited in the list of literature. A good and detailed discussion of it is to be found in chapter V of Preyer's *Physiologie des Embryo* ('85).

But there have been more extensive observations on the influence of temperature on the rate of growth in plants. The following table, taken from Vines ('91), p. 293, shows the increments in length of hypocotyls of various plants in forty-eight hours after Köppen and de Vries.

KÖPPEN.				DE VRIES.		
TEMPERATURE.	LUPINUS ALBUS.	PISUM SATIVUM.	LEA MAIS.	SINAPIS ALBA.	LEPIDIUM SATIVUM.	LINUM USITATISSIMUM.
14.1° C.	9.1 mm.	5.0 mm.				
15.1°	.....	.....	.....	3.8 mm.	5.9 mm.	1.5 mm.
18°	11.6	8.3	1.1 mm.			
21.6°	.....	.....	.....	24.9	38.0	20.5
23.5°	31.0	30.0	10.8			
26.6°	54.1	53.9	29.6			
27.4°	.....	.....	.....	52.0	71.9	44.8
28.5°	50.1	40.4	26.5			
30.2°	43.8	38.5	64.6			
30.6°	.....	.....	.....	44.1	44.6	39.9
33.5°	14.2	23	69.5			
33.9°	.....	.....	.....	30.2	26.9	28.1
36.5°	12.6	8.7	20.7			
37.2°	.....	.....	.....	10	0.0	9.2

TABLE IX. — Increment in length of hypocotyls in 48 hours, from Vines ('86), p. 293.

These figures are strikingly different in the relation of the maximum to the optimum from those which we have found

for animals. In all cases the maximum lies 6 to 8° above the optimum, and there is a very considerable decrease in the rate of growth from the optimum to the maximum. This is best seen in the following curve constructed from the above figures for *Lupinus albus*:

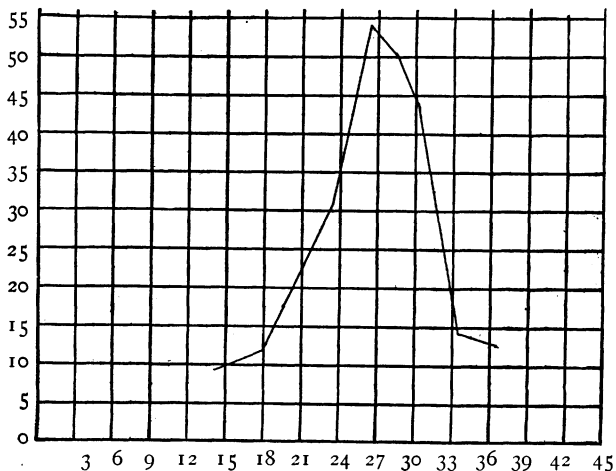


FIG. 5. — Curve of growth in length of the hypocotyl of *Lupinus albus* at different temperatures constructed from figures in Table IX. The ordinates represent growth in millimeters in 48 hours and the abscissae degrees Centigrade.

The ascending limb of the curve is very similar to the curves in Figs. 1-4. But the descending limb is much longer; in animals, indeed, it may be entirely wanting. This indicates that while the general law of increase in rate of growth is the same for animals as for plants, plants have in general become adapted to resist temperatures farther above the optimum temperature of development. May this not be due to the fact that animals in general can and do retreat from the higher temperatures of direct sunlight, while plants are of necessity subjected to them? Even developing embryos of animals which possess no power of locomotion of their own are placed so as not to be subjected to these high temperatures.

It is rather interesting to find that the curves given above resemble in general form the curves measuring the rapidity of known chemical processes at different temperatures. See Freer and Dunlap.

We do not think it possible to state any general law as to the effect of supramaximal and subminimal temperatures on the *form* of development. The effect differs surprisingly in different organisms. So far as we know, most observations on this point have been made by subjecting the form or eggs to be experimented on to the abnormal temperature for a short time only, and then allowing development to continue at a normal temperature. Our observations, on the other hand, were on the *continuous* effect of abnormal temperatures.

Hertwig ('94b) found that in twenty-four hours at 0° C. no development took place, and that when the eggs were restored to the room temperature, in some of them "a larger or smaller part of the vegetative half of the egg was permanently injured, so that it could not undergo cleavage and had to be gradually excluded from the healthy developing parts." Schulze ('94) doubts this, and concludes from his own observations "that the eggs of *Rana fusca* in the gastrula stage can withstand complete inhibition of the development (by cold) for fourteen days without any sort of injury." However, it is quite certain from our own observations that many eggs develop abnormally at 3° C., as already noticed.

Hertwig ('94a), p. 314, has also noticed that by raising the temperature of the water in which eggs of the frog are developing there is a certain point at which the lower pole is first injured and divides incompletely or not at all, while the black pole forms a disc of small cells.

Driesch ('93) observed that abnormally high temperature caused great variations in the cleavage and partial suppression of micromere formation in both *Sphaerechinus* and *Echinus*. In a later study ('94) he tested the effect of abnormally high temperature (30° C.) on the gastrulation of *Sphaerechinus*; exogastrulae were produced. If we suppose that the archenteron grows in the direction of least resistance, we must conclude, as Driesch points out, that the conditions of osmotic equilibrium within the blastula have undergone alteration as the effect of the high temperature.

## LITERATURE.

- '97 DAVENPORT, C. B. The Rôle of Water in Growth. *Proc. Boston Soc. Nat. Hist.* Vol. xxviii, No. 3. Abstract in *Science*. Vol. v, No. 115.
- '93 DRIESCH, HANS. Entwicklungsmechanische Studien: IV. Experimentelle Veränderungen des Typus der Furchung und ihre Folgen; Wirkungen von Wärmezufuhr und von Druck. *Zeitschr. f. wiss. Zool.* 53.
- '94 DRIESCH, HANS. Entwicklungsmechanische Studien: VII. Exogastrula und Averteria. (Ueber die Wirkung von Wärmezufuhr auf die Larvenentwicklung der Echiniden.) *Mitth. aus der Zool. Stat. zu Neapel.* xi.
- FREER, PAUL C., AND DUNLAP, F. L. On the Saponification of the Substituted Acetic Esters. *Am. Chemical Journal.* Vol. xiv, No. 5.
- '22 GASPARD, B. Einfluss der Temperatur auf die Entwicklung der Schneckeneier (*Helix pomatia*). *Magendie's Journal de Physiologie expérimentale et pathologique.* ii, 295, § 20. Paris.
- '96 GURWITSCH, ALEX. Ueber die formative Wirkung der veränderten chemischen Mediums auf die Embryo-Entwicklung. *Archiv für Entwicklungsmech.* iii, pp. 221-260.
- '94a HERTWIG, OSKAR. Beiträge zur experimentellen Morphologie und Entwicklungsgeschichte: I. Die Entwicklung des Froscheies unter dem Einfluss schwächerer und stärkerer Kochsalzlösungen. *Archiv für mikr. Anat. u. Entwicklungsgesch.* Bd. xlv, pp. 280-344.
- '94b HERTWIG, OSKAR. Ueber den Einfluss äusserer Bedingungen auf die Entwicklung des Froscheies. *Sitzungsber. der königl. preuss. Akad. d. Wiss.* xvii. 3 April, 1894.
- '78 MEYER, H. A. Abhängigkeit der Entwicklungszeit des Herings-embryo von der Wasserwärme. *Jahresber. der Commission zur wiss. Untersuchung der deutschen Meere in Kiel.* 4.-6. Jahrg. Berlin. pp. 207-240.
- '94 MORGAN, T. H., AND TSUDA, UMÉ. The Orientation of the Frog's Egg. *Quar. Journ. Micr. Sci.* Vol. xxxv, Part 3.
- '85 PREYER, W. *Specielle Physiologie des Embryo.* Leipzig. Th. Grieben. Chap. v. A. Einfluss der äusseren Temperatur auf den Embryo im Ei. pp. 343-359.
- '83 RAUBER. Einfluss der Temperatur, des atmosphärischen Druckes und verschiedene Stoffe auf die Entwicklung thierischer Eier. *Ber. der Naturf. Gesellsch. zu Leipzig.* 8 May, 1883.
- '94 SCHULZE, O. Ueber die Einwirkung niederer Temperatur auf die Entwicklung des Frosches. *Anat. Anz.* No. 9.
- '86 VINES, SIDNEY F. *Physiology of Plants.*